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BRIEF REPORT

Age-Related Differences in Transfer Costs: Evidence From Go/Nogo Tasks

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To assess whether age-related differences in suppressing nontarget material impact subsequent performance, the authors initially asked younger and older adults to perform a go/nogo task with colored letters used as conflicting go/nogo stimuli and 2 colored numbers as low-conflict nogo stimuli. Next, participants performed another go/nogo task. A previous number was reused as a nogo stimulus and the other as a go stimulus, with new numbers serving as a baseline. In a 1st block of trials, younger adults showed slower responses to previous nogo/now-go numbers than to new go numbers, an effect not shown by older adults. Alternative accounts of these differential transfer costs are discussed.

Keywords: normal aging, suppression, transfer cost, cognitive interference, go/nogo

Selective attention is the ability to choose goal-related targets and to ignore other information (Houghton & Tipper, 1994; Neill, 1977). Data from recent neuroimaging studies confirm a hypothesis first proposed by Hasher and Zacks (1988; Hasher, Zacks, & May, 1999) that the ability to select targets includes a suppression directed at nontargets for younger but less so for older adults, despite spared ability to process relevant information in aging (Gazzaley, Cooney, Rissman, & D'Esposito, 2005; Gazzaley & D'Esposito, 2007). There is also evidence that defective visual suppression of nontarget items, as measured with oscillatory electroencephalographic activity, is associated with lower memory retrieval of target information (Gazzaley et al., 2008; see Hamm & Hasher, 1992, for behavioral evidence).

Although most studies focus on the detrimental effects of poor attentional and neural suppression in aging on concurrent tasks, evidence that a suppression deficit at one moment can also have subsequent beneficial effects is starting to emerge. In one study (Rowe, Valderrama, Hasher, & Lenartowicz, 2006), younger and older adults had to initially ignore words superimposed on task-relevant pictures. They were then tested on a word-fragment completion task, to investigate implicit memory for the previously irrelevant words. The results demonstrated an advantage for previous distractors in older adults compared with their younger control participants (see also Kim, Hasher, & Zacks, 2007).

In another recent study (Vallesi, Stuss, McIntosh, & Picton, 2009), younger and older participants were tested on a go/nogo task while event-related potentials (ERPs) were recorded. There were two types of nogo stimuli: colored letters that created cognitive conflict with go letters (high-conflict nogo: red *O* and blue *X*; go: blue *O* and red *X*) and colored numbers (*2*, *3*) that did not create conflict with the go letters (low-conflict nogo) because they belonged to a different conceptual domain (numbers vs. letters). Performance on the nogo numbers was indeed at ceiling for both age groups, but older participants showed an enhanced central P3 for these stimuli, suggesting an increased need to inhibit inappropriate motor preparation (Roberts, Rau, Lutzenberger, & Birbaumer, 1994; Smith, Johnstone, & Barry, 2007). An additional ERP study demonstrated that older individuals, but not younger control participants, showed a partial response preparation not only for high-conflict nogo letters but also for low-conflict nogo numbers, as indicated by the lateralized readiness potential (Vallesi & Stuss, 2010), a measure of unimanual response preparation (Kutas & Donchin, 1980; Vallesi, Mapelli, Schiff, Amodio, & Umiltà, 2005).

Together, these findings suggest the possibility that older individuals have difficulty suppressing the perceptual, conceptual, and motor processing of nontarget material even when the information is easily distinguishable from targets. Although this suppression failure may not have any behavioral consequence in a given task context, it is possible that it influences performance when task demands change. The present study tested the downstream consequences of processing nontarget stimuli by younger and older adults. We did so in the context of an initial task in which no age differences were found on target performance. In particular, we tested motor control in an explicit go/nogo task to assess the generality of previous findings using implicit memory transfer tasks (e.g., Rowe et al., 2006), to measure age differences in the sustained influence of suppressing nontarget information when it becomes relevant.

To this end, we used a go/nogo task similar to that used in our previous studies (e.g., Vallesi & Stuss, 2010; Vallesi, Stuss, et al., 2009) as the first task, in which two numbers were used as

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low-conflict nogo stimuli, and then we assessed, in a subsequent go/nogo task, whether there was an age-dependent advantage in terms of speed when one of those low-conflict stimuli became a go stimulus (i.e., reduced or absent transfer costs). We note that this study extends previous findings because it addresses whether, even in the face of a single, simple stimulus (as opposed to the complex stimuli used in other studies, e.g., Kim et al., 2007), transfer of distraction will be seen. We note that if transfer is seen, it will be detected as a response time (RT) difference between old nogo/now go stimuli and completely new go stimuli.

Method

Participants

Twenty younger (12 women; mean age: 26 years, range: 19–34) and 20 older (11 women; mean age: 73 years, range: 64–81) volunteers took part in the study. The participants had normal or corrected-to-normal vision and no history of neurological or psychiatric disorders. All were right-handed as assessed with the Oldfield's (Oldfield, 1971) handedness questionnaire (range: 40–100). None of the older adults had dementia (score range on the Mini Mental State Examination: 27–30, $M = 28.5$). Participants provided informed consent before participating in the study, which was previously approved by the Baycrest Ethics Board.

Material and Tasks

Participants were tested individually in a sound-attenuated room. Visual stimuli were presented against a gray background of a computer screen at a distance of about 60 cm. Participants were initially informed about the fact that they would be presented with two tasks, but they did not know anything about the nature of the second task until they completed the first one. We shall describe the two tasks in detail in the following paragraphs.

Task 1: Letter–number go/nogo task. A similar task to that used in Vallesi, Stuss, et al. (2009) was used here. Go/nogo stimuli were letters and numbers colored in blue or red (50% each). Go stimuli were red *O* and blue *X*, and nogo stimuli were either blue *O* and red *X* (high-conflict nogo) or red and blue numbers *2* and *3* (low-conflict nogo). The association between color and go/nogo letters was counterbalanced between participants. Each trial began with a go/nogo stimulus lasting for 300 ms. A blank screen followed the stimulus presentation. The interstimulus-interval (ISI) range was 2.2 s–4.2 s to maintain comparability with previous similar studies (e.g., Vallesi, Stuss, et al., 2009).

Each block consisted of 64 go (50%), 32 high-conflict nogo (25%) and 32 low-conflict nogo (25%) stimuli. Stimulus types were presented in a random fashion. Participants were instructed to press *B* on a computer keyboard when a go stimulus occurred and not to respond to nogo stimuli. Participants performed two blocks of this task. Speed and accuracy were equally emphasized. A 2-s deadline was used to accept go responses. Each block was preceded by six familiarization trials (not included in the analyses).

Task 2: Number go/nogo task. In this second task, one of the two numbers already used in the previous task as nogo stimuli (*2* or *3*) was now used as a go stimulus and the other again as a nogo stimulus. The new numbers 5 and *6* were also used, one as a go and the other as a nogo stimulus to provide a baseline condition to assess transfer effects. The association between old/new stimuli and go/nogo responses was counterbalanced across participants. Each trial began with a go/nogo stimulus lasting for 300 ms. A blank screen followed the stimulus presentation. Visual stimuli were presented in black on a gray background. Since our main focus in this task was on age differences in transfer costs, the ISI was kept constant to 2 s in order to avoid possible confounds due to age-related differences in temporal preparation with variable foreperiods (e.g., Vallesi, McIntosh, & Stuss, 2009). Participants performed two blocks of this task. Each block consisted of 40 go stimuli (50% old and 50% new), and 40 nogo stimuli (50% old and 50% new). Stimulus types were presented in a random fashion. Participants had to respond by pressing "B" with the right hand to go stimuli and not to respond to nogo stimuli. Speed and accuracy were equally emphasized. Eight familiarization trials (not included in the analyses) were administered at the beginning of this task.

Data Analysis

Practice trials, the first trial of each test block, and go responses beyond 150–2000 ms in the initial letter–number go/nogo task and 150–1500 ms in the (easier) number task were discarded from further analyses. Trials with correct go-responses only were included in the analyses on the mean RTs. RTs produced as false alarms to nogo stimuli were not analyzed because they were too few. Go-RTs of the two age groups in the letter–number task were compared using a *t* test for independent groups. Go-RTs in the number go/nogo task were submitted to a $2 \times 2 \times 2$ mixed analysis of variance (ANOVA) with age (younger, older) as the between-groups factor, and familiarity (old, new) and block (first, second) as the repeated measures factors. To find the source of each significant effect, post hoc Tukey Honestly Significant Difference (HSD) Tests were run.

There was a significant main effect of age on the raw RTs, due to older participants being slower than younger control participants, $F(1, 38) = 10.5$, $p = .002$. Therefore, we transformed RTs to standard *z* scores to test the group differences independently of the age main effect and thus to attenuate a potential role of age-related general slowing. To obtain *z* scores for each condition and participant, we subtracted the mean RT of each age group from raw RTs of each individual of that group and divided the result by the RT standard deviation of that age group. We compared error percentages in the two groups using the nonparametric Kolmogorov-Smirnov Test, separately for each stimulus category. Cohen's *d* and partial η^2 were used to measure the effect size for significant effects in *t* tests and ANOVA, respectively.

Results

Task 1: Letter–Number Go/Nogo Task

Responses to go stimuli were slower in the older than in the younger group, $t(38) = 4.01$, $p < .001$, Cohen's $d = 0.43$; mean ± standard error of the mean: 712 ± 20 vs. 605 ± 18 ms. The error percentage was highest for the high-conflict nogo stimuli (5.2 ± 0.5%), relatively low for go stimuli (1.5 ± 0.5%), and at ceiling for the low-conflict nogo stimuli (0.16 ± 0.1%). One anticipation to go stimuli (RT < 150 ms) occurred only in a younger participant. There were no significant differences between the older and the younger groups in terms of accuracy to go (1 ± 0.5 vs. 2.1 ± 0.9%), conflicting nogo (4.2 ± 0.8 vs. 6.1 ± 0.5%), or irrelevant nogo (0.1 ± 0.1 vs. 0.2 ± 0.1%) stimuli (all *ps* $> .1$).

Task 2: Number Go/Nogo Results

There were no anticipations (RTs $<$ 150 ms) or late responses (RTs $>$ 1500 ms) for any participant tested. RTs to go stimuli in the number go/nogo task are shown in Figure 1, Panel A.

The ANOVA on the *z* scores of the go-RTs showed the following effects. A block main effect, $F(1, 38) = 4.9$, $p < .05$, Partial $\eta^2 = .11$, indicated that RTs decreased from the first to the second block. The Block × Familiarity, $F(1, 38) = 5.4$, $p < .05$, partial $\eta^2 = .13$, and Familiarity × Age, $F(1, 38) = 4.6$, $p < .05$, partial $\eta^2 = .11$, interactions were partially qualified by a three-way Familiarity × Block × Age interaction, $F(1, 38) = 8.3$, $p < .01$, partial $\eta^2 = .2$. This interaction indicated a different pattern of results in the two age groups. Younger individuals had longer RTs for go stimuli that were previously nogo than for new go stimuli in the first block ($p = .004$), a difference that disappeared in the second block ($p = .96$). In contrast, the RT difference between the two types of go stimuli in the older group suggests a facilitation for old nogo/now go stimuli with respect to new go stimuli, but this effect was, however, not significant in either block (*ps* $> .13$). To better appreciate this interaction, see Figure 1, Panel B, which plots the RT differences between go stimuli that were previously nogo and new go stimuli (baseline) for each block and age group.

Discussion

The present study explored age-related differences in the downstream effects of nontarget stimuli on subsequent performance, effects potentially attributable to age differences in inhibitory efficiency. In

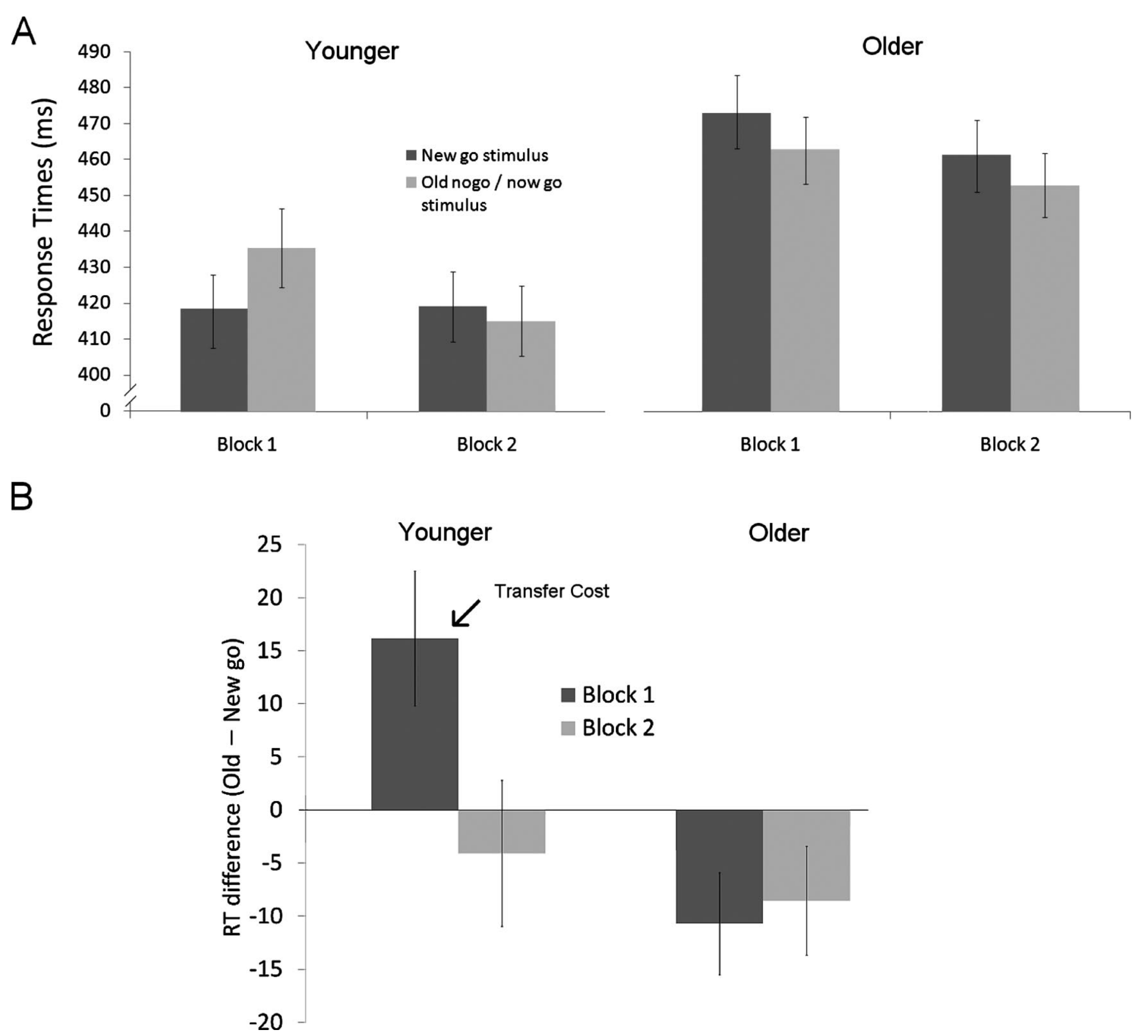

Figure 1. Panel A: Mean response times as a function of go condition, block, and age in the second go/nogo task (numbers only). Although the raw response times are displayed in the figure, we performed statistical analyses on the *z*-transformed data to rule out confounding effects of age-related slowing. Error bars represent standard errors of the mean. Panel B: Same data as in Panel A but now shown as the mean response time (RT) differences between old and new go stimuli for each block and age group. Error bars represent standard errors of the mean.

particular, the study investigated whether nonoptimal suppression of nontarget material in normal aging also occurs in the absence of detectable behavioral costs and, if so, whether the consequences of this selective attention failure could be observed in a subsequent task when the nontarget material becomes target. This phenomenon has already been shown in other domains, such as implicit memory (e.g., Rowe et al., 2006) and association formation (Campbell, Hasher, & Thomas, 2010), but this is the first study to investigate age-related differences in transfer of motor responses with go/nogo tasks. A secondary goal was to check whether reduced transfer costs in aging could also be detected when a single prime stimulus at a time is presented in the first task (a situation that is well within the processing capacity limits of the aging cognitive system).

The results demonstrate that nonoptimal suppression of information that has to be ignored (nogo stimuli) can have paradoxically beneficial aftereffects in aging. This was shown by an absence of transfer costs selectively in the older group when the task context changed so that this information became task relevant (go stimuli). This pattern is in contrast to that observed in younger adults, who showed a small but reliable cost in responding to go stimuli that had been irrelevant on previous trials. This transfer cost was seen in only the first block of trials, suggesting flexibility of the young cognitive system in overcoming long-lasting inhibition when this becomes an obstacle to optimal performance.

We note that a recent electrophysiological study found that low-conflict nogo stimuli, despite performance at ceiling, elicit an early preparation of a partial response in an older group only, as measured with lateralized readiness potential (Vallesi & Stuss, 2010; see Campbell et al., 2010, for similar behavioral evidence on conceptual processing). This partial response preparation for nogo stimuli is a sign of inhibition decline with aging, although it can additionally have a compensatory role since it showed a positive correlation with response speed for go stimuli.

Altogether, one way to interpret these results is that the failure to suppress processing of nontarget information in aging can prevent the occurrence of transfer costs, which has been mainly attributed to long-lasting selective inhibition of the to-be-ignored material. Although selective inhibition is the main mechanism used to explain transfer costs, other possible mechanisms can also account for the transfer costs observed here in the younger group but not in the older one. On an episodic retrieval account, for instance, transfer costs (such as in negative priming) originated from the implicit retrieval of information from previous trials when the current target had to be ignored (Neill, Valdes, Terry, & Gorfein, 1992). The occurrence of the same item led to the automatic retrieval of the previous processing episode(s) associated to it. Such episodes may contain information about the target/nontarget status of the items and the response they require (go vs. nogo). If there is a conflict in the retrieval episode, whereby an item previously encoded as *nontarget* is later coded as *target*, slower responses occur because the conflict between processing episodes must be resolved, not because of the inhibition occurring before.

A more recent study, which used a task manipulation similar to the current one, offered another explanation of the transfer costs observed in younger adults (Verbruggen & Logan, 2008). Consistent with the current findings, the authors found that responding to stimuli that were previously associated to a nogo response and, after extensive practice, was later mapped to a go response was slowed down in younger adults. The authors interpreted these results with an automatic inhibition account: Younger adults developed an automatic response inhibition with extensive practice during the first go/nogo task that relies on the association between stimuli and a nogo response; once the mapping between stimuli and go/nogo response was reversed, the automatic retrieval of such association was difficult to overcome and caused a cost with respect to new go stimuli.

When interpreted in the light of the latter account (Verbruggen & Logan, 2008), the current pattern of results would indicate that older adults do not develop an automatic association between a stimulus and the need to inhibit a response, which may imply two possible causes: (a) inhibitory processes are less efficient and do not become automatic in aging and/or (b) older adults do not learn associations between stimuli and go/nogo responses as efficiently as do younger adults. The first possibility, that is, that inhibition does not become automatic in aging, is supported by recent electrophysiological evidence that older adults fail to inhibit perceptual and motor processing of nontarget information, and show a subsequent pronounced inhibition-related P3 component (Vallesi & Stuss, 2010; Vallesi, Stuss, et al., 2009).

The second possibility, namely associative learning decline, may as well play a role here. Some forms of associative learning have been found to be impaired in aging (Naveh-Benjamin, 2000; Shing et al., 2010). However, unless strategic processes are required to form multiple associations or acquire complex task rules, which is unlikely for the low-conflict nogo numbers used in the first task here, more basic forms of associative learning are minimally affected or intact in normal aging (Levine, Stuss, & Milberg, 1997; Vallesi, McIntosh, & Stuss, in press; Woodruff-Pak, 2001; see also Campbell et al., 2010, for evidence of sparing of higher level associative learning). Finally, the fact that accuracy was matched on conflicting go/nogo letters in Task 1 (if anything, older adults slightly, although not significantly, outperformed younger adults with conflicting nogo stimuli) demonstrates that the older adults tested here had no binding problem, since they were able to combine stimulus identity and color to determine its go/nogo status. However, future research should assess more directly whether, not only a decline in inhibition efficiency, but also putative deficits in motor-related associative learning may contribute to the disappearance of transfer costs with aging.

At any rate, transfer costs represent the side effects of efficient attentional mechanisms that protect the cognitive system from interference derived from nontarget information. Some have argued that relevant stimuli are likely to be consistently relevant for an extensive period of time, and irrelevant stimuli tend to remain consistently irrelevant (e.g., Tipper, Weaver, Cameron, Brehaut, & Bastedo, 1991). Thus, either episodic retrieval or long-lasting inhibition of previous irrelevant material would generally facilitate coherent and fluid interactions with the environment. Only when the context changes so that previously irrelevant stimuli become relevant would a cost be apparent, at least until the new contingencies are acquired. As the present results show, these adaptive mechanisms are hindered with aging, although, under special conditions, this problem may paradoxically manifest itself as a temporary benefit, that is, as an absence of transfer costs.

One last possibility to consider is that in younger adults, repeated exposure to the same irrelevant stimulus (such as a word or a color) typically results in slower responses to the familiarized stimulus than to a comparable novel stimulus because of a habituation of brain responses to those stimuli (Fabiani, Low, Wee, Sable, & Gratton, 2006) and decreased alertness (Cecil, Kraut, & Smothergill, 1984; Kraut, Smothergill, & Farkas, 1981). However, the fact that responses to familiarized go (previous nogo) stimuli became faster from the first to the second block of the second task in the younger group rules out an alertness decrease account for repeated stimuli to explain the current pattern of results. A similar finding reported by Verbruggen and Logan (2008) also argues against an alertness decrease explanation: Younger participants in their experiments were faster in responding to current go stimuli that had already been presented as go stimuli in a previous task than to new go stimuli.

In conclusion, this study demonstrates that a decline in selective attention associated with aging can be detected even when no behavioral costs are observed in a given task. The consequences of this selective attention failure, which span different domains from the semantic level to the motor one, can be multifaceted and last for a considerable amount of time, ranging from costs to benefits depending on the task context.

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